Forensic Radiography: An Overview

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Perhaps the first instance of forensic radiography occurred in the 1890s when Professor AW Wright of Yale University tested Wilhelm Roentgen's newly discovered x-ray photography on a deceased rabbit. Of interest were small, round objects inside the rabbit that appeared as dark spots on the positive film. The objects were extracted and identified as bullets, thereby helping to determine the cause of the rabbit's death.[1]

In the years since Roentgen's discovery, the use of radiography and other medical imaging specialties to aid in investigating civil and criminal matters has increased as investigators realize how radiologic technology can yield information that otherwise is unavailable. Radiologic technologists can play a key role in forensic investigations.

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After reading this article, readers should be able to:

- *Define forensics and describe radiography's role in the science.*
- *List the different medical imaging techniques used in forensic radiography, along with their benefits in imaging different conditions.*
- *Describe how radiologic imaging differs between clinical and forensic settings.*
- *Understand the ethical issues and legal restrictions regarding forensics in general and forensic radiography in particular.*
- *Recognize the issues and challenges related to working in a forensic radiography setting, such as conditions and emotional effects.*

Forensics is defined as pertaining to, being connected with or used in a court of law. Forensic science applies scientific principles to investigating civil or criminal matters. Forensic radiography (see Box 1), then, is the performance of radiologic examinations to gather information that aids in civil or criminal investigations.[2] Forensic radiography includes both clinical imaging of the living and postmortem imaging. Clinical forensic radiography is used to examine people from a legal standpoint, such as to determine their age or prove a crime victim's injury. Postmortem forensic radiography involves scanning the deceased with imaging technology to obtain information that optimizes cause of death determination or identification (see Table 1).[4]

As a specialty, forensic radiography straddles medical imaging and forensics by using radiologic techniques to assist in legal matters. Although highly useful in determining the cause of death and identifying the deceased, forensic radiography is not formally recognized as a branch of forensic science.[2] For decades, conventional radiography was the modality used routinely for forensic purposes; however, computed tomography (CT) and magnetic resonance (MR) imaging are increasingly common in forensics today. Although CT and MR imaging provide the greatest potential for postmortem information, the way they are used in forensic imaging is very different from their use in medical diagnostic imaging examinations of living patients.[4]

Forensic radiography most commonly helps identify deceased individuals or remains and assists in determining the cause of death, but also is useful in imaging patients to investigate child or elder abuse,[2] medical negligence claims[5] and drug and jewel smuggling via "body packing."[6,7] Forensic radiography also is applied to inanimate objects to determine the validity of documents, the authenticity of fine art and jewels and to investigate suspicious packages.[1,2]

History of Forensics

The history of forensics can be traced back several thousand years, with the earliest record of a murder trial inscribed on a clay tablet in Mesopotamia in approximately 1850 BCE. In 44 BCE, the Greco-Roman era presented the next notable case requiring forensic attention when Antistius, a Roman physician, examined Julius Caesar's corpse after the dictator was assassinated. Antistius counted a total of 23 stab wounds on Julius Caesar's body but determined that only 1 wound to the chest was fatal. Also in the same era, Quintilian, an attorney in the Roman courts, proved that bloody handprints found at a crime scene were placed intentionally to frame a blind man of killing his own mother.[2]

Autopsies predate formal forensic science and first were performed to promote anatomical, medical and scientific study. The first law authorizing human dissection in the Western world was made under Holy Roman Emperor Fredrick II in 1231 and led to more lenient restrictions against opening the human body after death. In the 13th and 14th centuries in Italy, bodies more likely were opened for legal than medical purposes. It is documented that William of Saliceto, a Bolognese surgeon, performed at least 1 medical-legal autopsy between 1201 and 1280. In 1302, an autopsy was ordered to investigate the death of an Italian nobleman who presumably was poisoned.[8]

The widespread acceptance of autopsy began during the Renaissance, when human dissection was commonly performed in universities. Possibly the first documented case of consent for autopsy occurred between 1443 and 1502 when Antonio Benivieni, a physician in Florence, Italy, requested permission from the relatives of the deceased to perform postmortem examinations in cases of mysterious death. Also during this era, Leonardo da Vinci made anatomical sketches from approximately 30 human dissections. The first recorded autopsy in North America was an examination of conjoined twins in Santo Domingo, Dominican Republic, in 1533. The autopsy, however, was more religious than medical-legal in nature, having been performed to determine whether the twins had 2 souls or 1.[8]

The oldest existing book on forensic or legal medicine in any civilization is a Chinese text, translated as *Instruction to Coroners*, that was written in 1247. The book contains detailed instructions and procedures for investigating suspicious deaths.[2] In the United States, the Medico-Legal Society of New York was founded in 1883 as the first organization to institute an official investigative system. Marie-Francois-Xavier Bichat, possibly the first experimental pathophysiologist, made a correlation between pathologic findings and a physical diagnosis of disease late in the 18th century. The American Board of Pathology didn't begin certifying pathologists in North America, whose training relied heavily on autopsy, until 1936. Forensic pathology grew, and the medical examiner system began to replace the coroner system. In the United States, the autopsy rate increased from 12% in 1910 to almost 50% by the 1940s.[8]

Box 1
Explanation of Terms

The term *forensic radiography* is used throughout this Directed Reading rather than forensic radiology to address the work of the radiologic technologists who perform the imaging examinations. Radiology refers to the broad field of medical imaging, but radiography relates to recording or conducting the examinations. It is common in radiologic and other medical fields to use the term "imaging" to refer to a hospital's radiology department or the use of radiography and other diagnostic imaging modalities to examine patients. In the forensic sciences field, forensic imaging generally encompasses preparing and examining all photographic and videotaped evidence and preparing court exhibits vs radiography or diagnostic imaging specifically; therefore, the term is not used and all medical imaging specialties are encompassed under forensic radiography in this Directed Reading.

History of Forensic Radiography

What may be the first case of applying forensic radiography to a person occurred in 1896 in Montreal, Canada. A man named Tolson Cunning was shot and radiography was used to locate the bullet and ultimately help convict George Holder for attempted murder.[1]

Acceptance of findings from forensic radiography as valid evidence in a court of law was not as forthcoming as discovery of the technology. In 1919, a court in Iowa allowed the admission of radiographs as evidence but disallowed expert testimony to explain the findings. Instead, a physician witness was allowed to describe the findings one would expect on a radiograph; the jurors viewed the images and made their own conclusions. Other forensic applications of radiographs were documented in the *Journal of the American Medical Association* in 1896; they included the demonstration of fractures, bullets and "other known peculiarities," as well as the use of radiography to examine suspicious packages,

Table 1
Formal Forensic Disciplines [2,3]

Discipline	Description
General toxicology	Examining body fluids (blood, urine, spinal fluid) or tissues (organ or muscle) for substances, such as drugs or poisons
Firearms/toolmarks	Determining matters such as whether a bullet was fired from suspect weapon; comparing toolmarks left at a crime scene or on a victim against test marks made in a laboratory by suspect tools (knives, screwdrivers, pliers, etc)
Questioned documents	Examining, comparing or analyzing questioned documents (checks, driver licenses, contracts, wills, threatening letters, suicide notes, etc), to establish authenticity, expose forgery or reveal alterations
Trace evidence	Examining physical evidence — ranging in size from microscopic to visible with the unaided eye — that results from the transfer of minute quantities of materials (hair, fibers, paint chips, glass fragments, etc)
Controlled substances	Examining evidence (plant material, powder, drug paraphernalia, tablets/pills, etc) to identify drugs
Biology/serology screening	Testing for the presence of blood, semen, saliva or other body fluids; using chemical or microscopic tests to determine whether samples subsequently undergo DNA testing
Fire debris/arson analysis	Examining items or debris from the scene of a fire to determine whether a fire was deliberately set
Impression evidence	Examining objects or materials (hard flooring, dirt, mud, dust, etc) that have retained characteristics of other objects (fingerprints, tire tracks, etc) that were physically pressed against them; includes investigating latent prints, which are impressions made by contact of bare hands or feet on a surface that are not readily visible
Blood pattern analysis	Analyzing bloodstain patterns at a crime scene, which can help in reconstructing an incident
Crime scene investigation	Recovering and analyzing forensic evidence, as well as addressing issues of security, prevention of contamination, locating and collecting evidence, interpreting evidence and reconstructing an incident
Medical-legal death investigation	Analyzing sudden, unnatural, unexplained or suspicious death (homicide, suicide, unintentional injury, drug-related death, etc) by determining cause and manner of death, which depends on jurisdiction and the responsibility of pathologists, medical examiners or coroners
Digital evidence	Examining all digital forms of evidence related to a crime (forensic imaging, audio, video, computer files or other computer data, etc)

which remains a relevant way to apply the technology more than 100 years later.[1]

The Medical Examiner vs Coroner System

In modern American society, a distinction is made between a medical examiner and a coroner. A medical examiner is a board-certified forensic pathologist who typically leads the forensic department. The coroner most often is an elected official who may or may not be educated in forensics and pathology.[2] As of 2004, the Centers for Disease Control and Prevention (CDC) reported that 21 states had a medical examiner system, 10 had the coroner system and 19 a mixed system.[9]

Medical-legal investigation of death can be centralized (ie, from 1 office at the state level) or decentralized (ie, from more than 1 location at the regional, county or city level). Twenty-three states and the District of Columbia have centralized systems and

27 states have decentralized systems. Medical examiner or coroner offices may be affiliated with the public health department or public safety department or may be independent of any government agency.[9]

Radiography

Forensic radiography usually is performed in a morgue. Conventional radiography remains the most common modality used in the forensic setting and equipment ranges from a simple mobile unit to a more advanced fixed radiographic unit. Other modalities include CT, MR imaging and a combination of modalities. In general, the type and scope of radiographic equipment used in the forensic setting is determined by need, resources and budget constraints.[2]

Gunshot Wounds

Because gunshot wounds are the most common cause of homicide in the United States,[10] analyzing and interpreting these injuries is of great importance to forensics. Radiography is a useful tool for imaging both living and deceased victims of gunshot wounds because it demonstrates the beveling of bones from a bullet's impact, and indicates entrance and exit wounds.[11]

Radiography demonstrates both the soft tissue and the bony structures for examining craniocerebral gunshot injuries (see Figure 1). This ability to view both the soft and hard structures on radiographs made a life-saving neurosurgical operation possible in a patient who sustained a gunshot to the head. Preoperative head radiographs demonstrated the characteristic crater-like bone defects of the entrance and the exit wounds, which were misdiagnosed on the hospital medical records.[12]

Beveling in exit wounds to the head is assessed by measuring the endocranial and ectocranial size of a wound. By locating the area with the most pronounced beveling, the examiner can determine whether there is a correlation between the direction of the beveling and the direction of the bullet path. Typically, outward beveling indicates an exit wound. Exit wounds most often are round, oval, square or rectangular, but they always are more irregular than entry wounds. In an analysis of 21 cases of gunshot wounds, external beveling of the exit wounds was found in the vault bones but not in the orbit, maxilla and greater wing of the sphenoid, temporal or left occipital bones.[13]

Entry wounds, in contrast, usually are round or oval, but may be misshapen (ie, triangular, almost rectangular or otherwise irregular) in bones such as the mandible

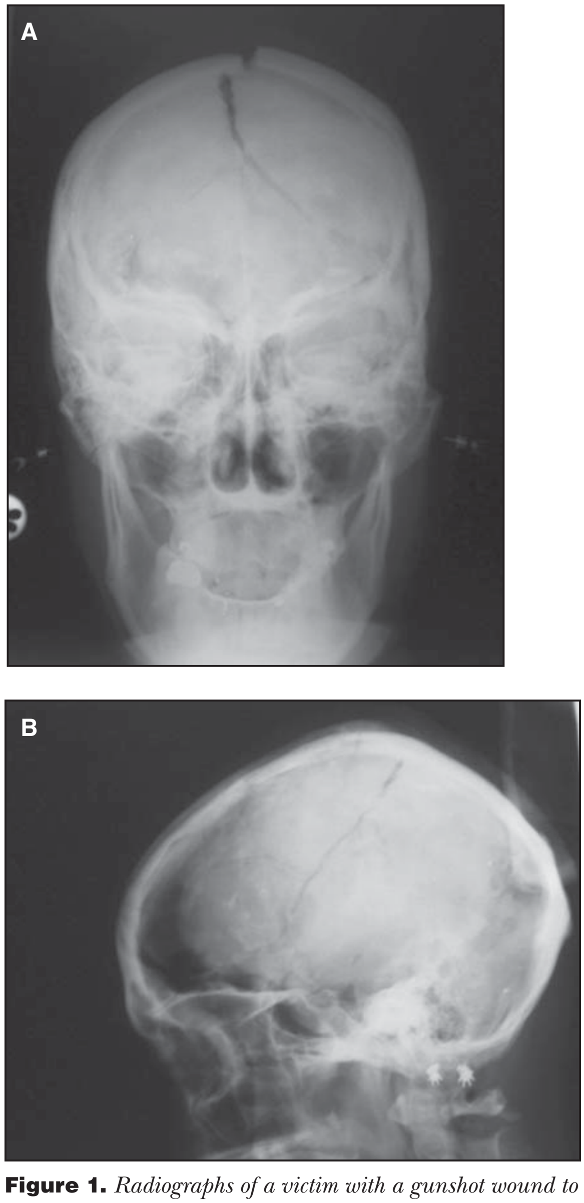

Figure 1. *Radiographs of a victim with a gunshot wound to the forehead. A. Frontal projection. B. Lateral projection. The bullet entered just above the left eyebrow and exited posteriorly. The autopsy clearly demonstrated damage to the brain and the exit wound in the posterior scalp. Images courtesy of Nancy Adams, BSRS, R.T.(R), Itawamba Community College, Fulton, MS.*

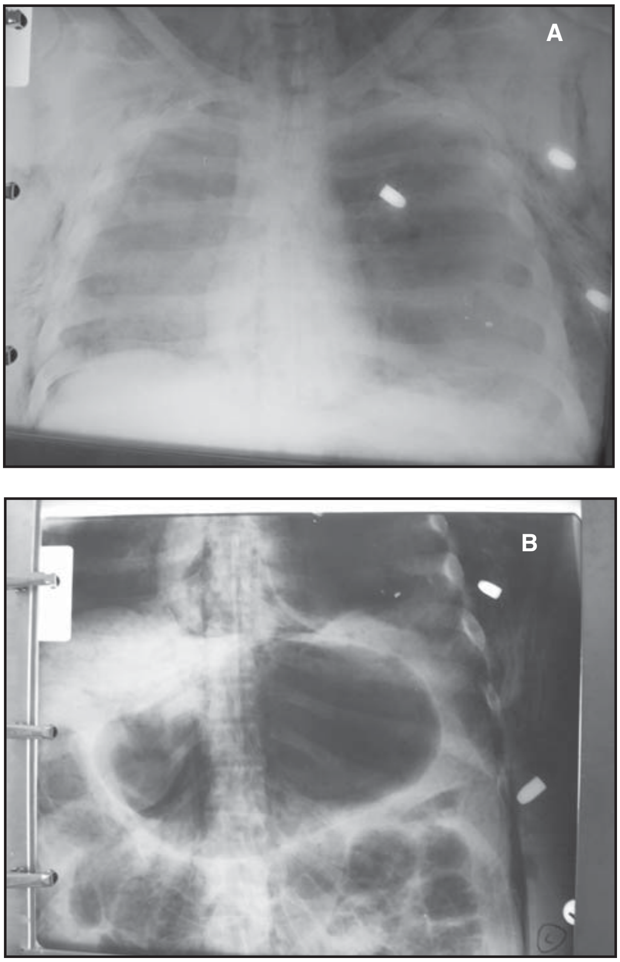

Figure 2. *Radiographs of a victim who died from multiple gunshot wounds. A. The first exposure taken revealed 3 bullets. The rib fracture and bullet fragment in this image were used as landmarks for the radiograph in: B. This radiograph reveals the fourth bullet. The victim weighed approximately 350 lbs, which complicated locating the other bullets during autopsy. Images courtesy of Nancy Adams, BSRS, R.T.(R), Itawamba Community College, Fulton, MS.*

and mastoid process. Furthermore, tunneling sometimes occurs from gunshot wounds in the mastoid process.[13]

In general, when 2 fracture lines of a solid surface (such as the skull) intersect, the chronology of the fractures can be determined because the pre-existing fracture blocks all other fracture lines produced by subsequent damage. This principle, established more than 100 years ago, is applied today in sequencing blunt force trauma or determining the direction of fire for gunshot injuries.[14] The principle also helps distinguish entrance from exit wounds when there are no other defining features, such as internal or external beveling of the skull or overlying skin indicators.[11,15]

The radiologic technologist can assist with assessing gunshot wounds to the neck of a living victim by clearly understanding the anatomy. These injuries are particularly dangerous because multiple vital structures are concentrated in this small anatomical area. The mass and velocity of the projectile determine the upper limit of possible tissue damage, and an analysis should include mapping the projectile path with conventional radiography and CT. This allows the extent of the wound to be further evaluated by showing how the projectile fragmented and any secondary projectile paths.[16]

In tandem, interpreting forensic radiography and reconstructing the circumstances surrounding a gunshot incident and victim help determine a cause of death and assist law enforcement with a criminal investigation (see Figure 2).[17]

Accidental Death

Radiography along with physical examination can determine cause of death when it may be accidental. For years, radiography has helped identify or confirm fractures in victims of nonaccidental and accidental death. Motor vehicle accidents often cause injuries to the cervical spine (see Figure 3). Most C-spine injuries from motor vehicle accidents occur between C4 and C7. Many of these injuries are difficult to detect, including intervertebral disk lesions, facet joint fractures and injuries to the joint capsules or ligaments.[18]

Identifying the Deceased

One of the most accurate ways to identify the deceased is to compare antemortem and postmortem radiographs.[19] Radiographic findings are greatly enhanced by physical findings and an individual's medical history, when available. For example, a positive identification was made on the body of a truck driver found burned beyond recognition after a collision. Because the individual's medical history included a dislocated right shoulder, the radiographic finding of typical Hill-Sachs lesion — an impaction fracture of the humeral head associated with anterior location of the shoulder — allowed identification. Many fractures and diseases leave an indelible and

Figure 3. *Although numerous fractures from a motorcycle accident were associated with this victim, the cause of death was determined to be anterior dislocation of the cranium on the atlas (internal decapitation), as shown in this cross-table lateral radiograph of the cervical spine. Image courtesy of Nancy Adams, BSRS, R.T.(R), Itawamba Community College, Fulton, MS.*

distinct mark on the skeleton, which can aid in identifying the deceased when those details are paired with individual medical history.[20]

Determining sex is vital to making a positive identification of the deceased. Kranitoti et al established a method for determining sex using digital radiography of the proximal epiphysis of the femur. In the study, 70 left femurs (36 from men and 34 from women) were measured according to standard osteometric techniques. The researchers then examined the proximal epiphyses of the same sample with digital radiography. Six characteristics of the bones were selected in the images, and 15 variables representing all possible combinations of these characteristics were calculated, resulting in a 92.9% accuracy rate of sex determination. Digital radiography proved more accurate in determining sex than conventional methods. The authors concluded that this method is valuable in forensic investigations of mass disasters or crime scenes when the only remains are semidecomposed or charred, maceration is not an option and osteometry does not apply.[21]

Nasal and sinus structures also may help in identifying the deceased. In a study of 209 forensic pathology cases and 163 clinical cases, skull radiography was used to image and compare nasal septum deviation patterns (straight, left, right, sigmoid, reverse sigmoid and other rare types) and frontal sinus patterns (aplasia, symmetry, left or right dominant asymmetry combined with the number of lobulations). The nasal and sinus patterns then were compared to create a classification system of at least 204 different combinations. This classification is thought to be potentially helpful in identifying unknown human remains.[22]

Identifying Control Injuries

Control injuries, which result from operating a vehicle, aircraft or other vessel, may assist with piecing together mysteries from fatal accidents. Control injuries usually involve the hands and lower extremities and are caused by a driver or operator's contact with control instruments. In a retrospective study of a helicopter accident resulting in 2 fatalities, forensic pathologists assessed digital radiographs and multidetector computed tomography (MDCT) scans. The imaging allowed investigators to view the skeletal fractures, where metal fragments were located in the bodies and other pathologic findings. Although the radiologic imaging supplemented traditional autopsy, it also allowed forensic pathologists to determine control injuries. Because control injuries are associated with the pilot, pathologists were able to determine which victim was the pilot of the aircraft.[23]

Medical Negligence

Radiography and other modalities can help prove medical negligence, such as the case of a 70-year-old man who died 1 hour after being involved in a minor motor vehicle collision. The postmortem examination failed to show any potentially fatal injury, but more in-depth macroscopic examination identified myocardial necrosis accompanied by massive bleeding in the anterior left ventricle. The investigation found that the man had been diagnosed with ischemic heart disease from severe stenosis of the left anterior descending coronary artery (LADCA) and subsequently received a stent implantation 1 month before the collision. Microscopic examination showed myocardial necrosis accompanied by hemorrhage and granulation tissue in the anterior wall of the left ventricle. Radiographs confirmed an intracoronary stent. Stent thrombosis was not evident, but investigators believed that the occlusion occurred in a branch or branches of the LADCA. In this case, radiographic examination effectively served as an adjunct to forensic pathology in helping to identify the stent and subsequent medical complications, which ultimately were the cause of the man's death.[5]

Smuggling and Suspicious Objects

Radiography often helps investigators identify drugs smuggled by body packing, although CT is used occasionally. Body packing involves a condom, balloon or other small, rubber or latex packet filled with illicit drugs and sealed with tape, wax or other material[6] that is inserted into the body, usually via the rectum. Smugglers may be detained by local authorities or fall gravely ill when the smuggled drugs seep into their bodies through a tear or hole in the packaging. Abdominal radiography performed with the individual in an upright and a supine position confirms the smuggling. On a radiograph, hashish is denser than stool, cocaine appears similar to stool and heroin has a gaseous transparence. These findings vary depending on the purity of the drugs. The packets typically are uniformly sized and round or oval in shape.[7]

Radiography also may aid in identifying other forensic evidence, such as diamonds that have been ingested by smugglers. Customs officers also may use radiography to examine suspicious baggage.[19]

Child Abuse

Shaken baby syndrome is a common form of child abuse and can be determined through radiography. Shaken baby syndrome is associated with a poor prognosis and high incidence of death.[24] It occurs when an adult violently shakes an infant or child, usually in response to the child's crying.[25] Injury can occur quickly, sometimes within 5 seconds, even if the child's head does not come into contact with a physical object.[26] Because many infants and children do not show outward signs of abuse, diagnosis can be difficult. Shaken baby syndrome is identified by a triad of symptoms: retinal hemorrhage, subdural hemorrhage or hematoma and a medical history void of a valid explanation for cerebral trauma.[27] Long-term symptoms include permanent brain damage, visual impairment or blindness, disabilities and motor impairments, paralysis, hearing loss or seizures.[24] Less than 35% of infants and children who survive shaken baby syndrome develop normally.[28]

The American College of Radiology (ACR) created appropriateness criteria for radiologic examination of injury in children suspected of being abused. These criteria can help determine the most appropriate radiologic modality depending on a child's age, signs and symptoms. According to the ACR grids, radiography is the preferred method for examining children 2 years or younger who have no focal signs or symptoms, along with those who have head trauma and no neurologic abnormality. In children up to 5 years of age, radiography or CT is preferred for examination of children experiencing seizures or neurologic signs and symptoms, with or without physical findings, and children who have visceral injuries, suspect medical histories or inconclusive physical or laboratory examinations.[29]

The American Academy of Pediatrics offers a policy statement on diagnostic imaging of child abuse. This statement says that radiologic imaging can be critical in assessing infant and child injuries resulting from abuse. Such injuries include certain types of skeletal trauma, head trauma or thoracoabdominal trauma. The skeletal survey generally is the imaging method of choice for suspected skeletal abuse.[30]

Cross-sectional Imaging

Gunshot Wounds and Other Injuries

CT can be used alone or as an adjunct to traditional autopsy to examine gunshot wounds and other injuries. According to a study of 20 cases of fatalities from beatings, stabbings, gunshots, fires and motor vehicle accidents, CT was more effective in documenting certain findings that commonly are missed when performing traditional autopsies, including gunshot wounds and bone fractures.[31] In the living, CT is the standard diagnostic tool for examining tissue damage from gunshot injuries. CT images can help determine the type of gun used because certain injury characteristics have been linked to specific types of guns.[32]

A study of 14 patients who had sustained gunshot injuries to the viscerocranium within 10 years before the study found that injury characteristics directly corresponded with the type of gun used. The injuries occurred in the oral and craniomaxillofacial areas and were examined using cone-beam CT. High-density projectiles do not cause severe artifacts with cone-beam CT, as they can on conventional CT images. This helps in evaluating anatomic structures close to the projectile and makes cone-beam CT more suitable for diagnostic imaging of high-density projectiles. Based on clinical and radiological diagnosis using CT and cone-beam CT, investigators directly correlated the gun or projectile and the diameter of the wound track, tissue contamination and tissue destruction. They discovered that the patients' injuries were caused by 8 combinations of handguns or long guns with soft lead core projectiles, partial or full metal-jacketed bullets or different propellants. Furthermore, entrance and exit wounds indicated certain projectile combinations.[32]

CT and MR imaging are useful in evaluating gunshot wounds to the head, according to a study by Oehmichen et al. In this study, the researchers examined 17 cadavers with gunshot wounds to the head with the 2 imaging modalities. Fifteen of the 17 victims had a penetrating wound to the head; the other 2 had a bullet lodged in the brain. All the gunshots were from guns with low muzzle energy (< 500 J), such as handguns and low-velocity rifles. In some cases, imaging was performed before autopsy and in other cases, the formalin-fixed brain was imaged after autopsy. All images were correlated with the criminological data and the results of both macroscopic and microscopic examination. CT and MR imaging of the cerebral parenchyma showed opaque bone and projectile fragments along the bullet's course. Both modalities demonstrated the angle of trajectory, the entrance and exit wounds and the extent of tissue damage along the projectile path.[33]

Drowning

A study by Rafaat et al showed that cranial CT effectively aided diagnostic and forensic objectives in examining children who drowned. The objective of the study was to better define the type and incidence of cranial CT abnormalities in children with submersion injuries. Cases (N = 156) were selected from a registry of drownings that occurred between January 1989 and April 2006. The researchers chose only patients admitted to the hospital with a diagnosis of drowning who received a cranial CT within 24 hours of submersion. The majority of patients (82%) had normal findings on the initial CT scans, whereas 18% had abnormal CT scans. The abnormal findings included diffuse loss of gray-white differentiation (75% on presentation) and bilateral basal ganglia edema/infarct (50% on presentation). There was no evidence, however, of intra-axial or extra-axial blood or unilateral findings in any of the abnormal scans. These findings differ from those of patients who have suffered abusive head trauma and can help pathologists determine whether drowning was the cause of death in children.[34]

Skull Reconstruction

In an analysis of 10 forensic autopsy cases, CT scans were performed before death to create a spatial reconstruction of the fractured skulls. All patients had been hospitalized and received CT scans only days before they died. Photographs of the skull fractures were taken in the postmortem examinations. CT scans stored in digital imaging and communications in medicine (DICOM) format using an eFilm workstation (Merge Healthcare, Milwaukee, Wisconsin) and ImageJ software (freeware in the public domain authored by Wayne Rasband at the National Institute of Mental Health in Bethesda, Maryland) were computed to create a spatial reconstruction of the skull. The reconstructed image demonstrated the fractures, which the authors compared to those shown in the photographs. Results suggested that the CT scans performed in the clinical setting were typically insufficient for forensic purposes but provided an important source of additional information, especially when the autopsy report was inconclusive.[35]

Decomposing Bodies

Because it is noninvasive, CT can help in determining the cause of death of a decomposing body. When conventional radiography cannot document the representative anatomy, CT can help construct 2-D and 3-D images before an autopsy is performed. Because use of CT allows the body to remain closed, the resulting images can show gaseous distention of the decomposing organs and tissues in detail. MDCT also can help rapidly screen for foreign matter in decomposing bodies.[36]

Determining Type of Force

CT facilitates studying the auditory ossicles, which are minute bones in the ear that are difficult to examine in a traditional autopsy. Any lesions in these bones caused by force often are overlooked or disrupted by the autopsy procedure. In a study of 100 cases by Hollinger et al, postmortem MDCT was used to examine auditory ossicle luxation and petrous bone fractures. The authors concluded that the type of force, not the amount of force to the head, caused the lesions.[37]

Accidents and Trauma

CT and MR imaging may demonstrate minor injuries from motor vehicle accidents more effectively than conventional radiography. Uhrenholt et al investigated

20 cases of fatalities from motor vehicle accidents and compared the victims' injuries with 22 people who died from nontraumatic causes. The investigators used conventional radiography, CT and MR imaging to identify occult injuries in the facet joints of the cervical spine. They reported that cross-sectional imaging, particularly CT, detected facet joint fractures in many of the individuals killed in a motor vehicle crash.[18]

Combined use of CT and MR imaging helps identify certain types of chest trauma in postmortem examinations. The cross-sectional imaging produced by these modalities gives them an advantage over a conventional autopsy. In a retrospective study by Aghayey et al, 24 victims of chest trauma were examined with CT, MR imaging and an autopsy. The radiologists who analyzed the data were not allowed access to the autopsy findings. CT and MR imaging combined yielded 75% to 100% of the findings. These modalities identified pneumomediastinal, pneumopericardial and pericardial effusion, conditions that were not noted in the autopsy report. The authors concluded that the combination of postmortem CT and MR imaging provides a useful adjunct to an autopsy for assessing chest trauma in forensic medicine.[38]

Hepatic Injury

A comparative study of MDCT and MR imaging found that although the modalities did not find many cases of small organ injury, the methods detected most life-threatening injuries to the liver, which is important in forensic pathology. The purpose of the study was to determine, on the basis of 34 cases of preautopsy imaging, the sensitivity and specificity of postmortem CT and MR imaging in detecting abdominal injuries after major blunt trauma. Comparison with autopsy findings showed the highest sensitivity and specificity in detecting major liver lacerations when CT and MR imaging were combined. Together, the modalities also had 100% specificity in detecting renal trauma, but sensitivity of only 25%. When the modalities were separated, the ability to detect hepatic injury was markedly lower. In particular, imaging hepatic injury with CT alone resulted in 53% sensitivity and 84% specificity. MR imaging alone had a sensitivity of 58% for liver injuries and a specificity of 46%.

Child Abuse

CT and MR imaging often are used along with radiography to study suspected cases of shaken baby syndrome.[24] Skeletal trauma and general suspected abuse may be examined using cross-sectional imaging. American Academy of Pediatrics and ACR guidelines help to determine which children are candidates for CT or MR imaging based on age, signs and symptoms.[30]

Postmortem imaging was performed before the autopsy in an investigation of the death of a 17-month-old child who died from unknown causes. External examination revealed diffuse ecchymoses of varying color. Radiologic examination consisted of radiography, MDCT and focused brain MR imaging. Results indicated rib fractures of varying ages, cerebral and pericerebral traumatic lesions, bilateral subdural hematomas and intraventricular, meningeal and interpeduncular hemorrhages. Fresh blood also was found in the anterior abdominal wall and the mesenteric root. In this case, radiologic imaging provided important information that led investigators to determine child abuse.[40]

Strangulation

MR imaging has shown high sensitivity and specificity in demonstrating the severity of manual strangulation. In a study of 56 survivors of manual strangulation, forensic pathologists and 2 radiologists in blinded interpretations assessed case histories, clinical examination and MR imaging scans to create a scale of radiologic signs of danger to life from strangulation that spanned from life-threatening to nonlife-threatening. The neck was divided into 3 cross-sectional zones: superficial, middle and deep. Using MR imaging, the defining characteristics of life-threatening strangulation were intramuscular hemorrhage/edema ($P = .02$), swelling of the platysma ($P = .02$), intracutaneous bleeding ($P = .02$), subcutaneous bleeding ($P = .034$) and hemorrhagic lymph nodes ($P = .04$). Using these findings, it was determined that strangulation was life-threatening in 15 (23%) of cases and nonlife-threatening in 41 (73%) of cases. This system showed a sensitivity and specificity of approximately 70% for detecting life-threatening strangulation when at least 2 neck zones were affected. Investigators stressed that MR imaging is highly effective in documenting strangulation and that the images it produces are admissible in a court of law.[41]

A separate study of 14 strangulation survivors found that MR imaging effectively demonstrates life-threatening strangulation and danger to life, which are both important to a forensic investigation because they affect the extent that a perpetrator may be prosecuted under the law. The study authors added that the best method to classify strangulation involves considering radiologic findings of the inner neck in addition to typical external findings because external signs might not indicate the full degree of danger to life.[42]

Hanging

MR imaging confirmed laryngoscopic findings in an investigation of 5 deaths from hanging. Results were compared with 3 controls, who died from events other than hanging, along with injuries discovered during autopsy. In all 5 hanging cases, laryngofibroscopic investigation revealed a vocal fold position in complete adduction, which MR imaging confirmed. In contrast, the vocal cords of the 3 controls were found to be in the intermediate position. The results from the laryngofibroscopic examination, confirmed by MR imaging, suggested that pressure on the cervical nervous and cartilaginous structures or their elongation during hanging could lead to closure of the glottis with vocal cord adduction after death. Furthermore, these techniques provide information that may assist in understanding asphyxia phenomena in hanging victims.[43]

Characterizing Counterfeit Pharmaceuticals

Radiologic imaging can effectively identify and characterize counterfeit pharmaceuticals. The production of counterfeit drugs has increased over the past decade. Reports of counterfeit artesunate-based antimalarial drugs have increased because of the high demand for and rising costs of authentic antimalarials. Counterfeit antimalarials can cause death and contribute to drug resistance, which is a growing problem, particularly in Southeast Asia. In a study by Nyadong et al, researchers compared 2-D diffusion-ordered MR spectroscopy, desorption electrospray ionization mass spectrometry and real-time mass spectrometry, and tested their effectiveness in pharmaceutical forensics. Investigators assessed 14 different artesunate tablets that were representative of the counterfeit antimalarials available in Southeast Asia. Using MR and mass spectrometry, investigators detected the active pharmaceutical ingredient in only 5 tablets. MR results were used to establish counterfeit drug chemotyping, which is a method for determining a chemically distinct entity among drug formulations. Furthermore, MR imaging provided spatially resolved (ie, a measurement of the smallest area identifiable on an image as a discrete unit) information about the surface composition of counterfeit and authentic antimalarial formulations, helping to demonstrate the homogeneity of both counterfeit and authentic samples.[44]

Virtual Autopsy

The virtual autopsy, also called virtopsy, is an emerging imaging technique that combines 3-D optical techniques, MDCT and MR imaging to conduct a minimally invasive autopsy. The procedure is similar to laparoscopic surgery in clinical medicine and is showing great promise in the field of forensics. The bloodless technique demonstrates the interior of the body without dissection. A medical team at the University of Bern's Institute of Forensic Medicine in Switzerland pioneered the virtual autopsy and is developing the procedure further.[45]

In a virtual autopsy, 3-D surface scanning documents the body's surfaces and MDCT and MR imaging provide views of internal structures. This is important in forensics because 3-D imaging can help document injury patterns. Furthermore, virtual autopsy allows for re-examining a corpse decades later, even after burial or the subsequent discovery of a crime scene.[46]

The virtual autopsy technique has proven effective in identifying foreign objects in the larynx, which is a common cause of death found on autopsy. In 3 cases of suspected choking from a foreign body in the larynx, MDCT and MR imaging were performed before a standard autopsy. MDCT showed high diagnostic power in locating foreign bodies and abnormalities in the larynx, although its power to differentiate neoplasms from soft foreign bodies was low. MR imaging was better at differentiating between soft-tissue structures and soft foreign bodies. Overall, the 2 imaging modalities proved highly effective, noninvasive means of detecting foreign objects in the larynx.[45]

Virtual autopsy also can detect findings that are otherwise occult or difficult to detect in a standard autopsy, such as internal bleeding (brain contusion, blood aspiration to the lungs), bullet paths and missile fragmentation and hidden fractures.

The primary benefit of virtual autopsy is that it is noninvasive and does not destroy human tissue. This makes it an acceptable tool when religious beliefs prohibit dissection required for standard autopsy. This technique currently is not meant to replace standard autopsy, but rather is an alternate tool when dissection is not possible or additional forensic evidence is needed.[47]

Other Uses of X-rays and Imaging

Forensic pathologists produce the information they need through a number of analytical methods. Many of these methods require highly sophisticated computers and software.[48] Some involve x-rays and similar technology normally not associated with diagnostic medical imaging. For example, the cause of death of a football fan who had been shot with a parachute flare in the leg was investigated. The inspectors examined the victim's pants and parts of the flare removed from the leg wound with an optical microscope, a scanning electron microscope and an energy dispersive x-ray spectrometer. They found burn marks on the upper front of the man's pants, including a 35 to 40 mm circular hole with melted and charred edges. Postblast residue on the surface of his pants contained strontium, magnesium, potassium and chlorine. Witness testimonies and medical reports following the accident combined with this evidence determined that another person located some distance away had shot the victim with a parachute flare.[49]

High-performance liquid chromatography (HPLC) — a form of column chromatography that separates, identifies and quantifies compounds — may be used in forensic toxicology. In a study of 8 antidepressants and their metabolites, HPLC with diode array detection helped identify and quantify 1 or more of the drugs in plasma after an overdose.[50] Similarly, investigators used HPLC with fluorescence and ultraviolet detection to recover 3 antidepressants (the serotonin reuptake inhibitors citalopram, fluoxetine and paroxetine) in whole blood and plasma.[51]

Mass spectrometry, a form of HPLC, identifies chemicals in a substance by their mass and charge. The technology has helped detect a wide range of pharmaceuticals in human hair. With this method, 75 mg of powdered hair are incubated for 12 hours in distilled water or hydrochloric acid. Both the liquid and the gas chromatographic techniques separate the drugs, and photodiode array and mass spectrometric detection identify the drugs. Identification was achieved using reference data from 675 pharmaceutical medications, along with toxicants and other drugs. In addition to establishing a victim's drug history, mass spectrometry serves as a powerful tool in forensic medicine by helping to identify toxic substances that may contribute to an individual's death.[52]

Mass spectrometry also can identify substances other than drugs, such as ciguatera, a type of food poisoning associated with the consumption of certain tropical fish. Fish samples were investigated with reversed-phase mass spectrometry and tandem mass spectrometry to detect the ciguatoxin in a postmortem human liver sample.[53]

One drawback of using HPLC techniques is that they require highly specialized training, which puts them out of reach financially for small forensic departments with limited budgets and resources. Also, there is growing awareness of the limits of HPLC, such as problems with selectivity and potential signal interferences, which can lead to false-positive results.[54]

In forensics, 3-D computer imaging creates facial and skeletal models of the deceased to help identify subjects and for other uses. Advances in 3-D imaging also allow for facial re-creation of living suspects. One such development is geometrically compatible imaging, which scans a 3-D facial model of a suspect and compares it to the 2-D video surveillance of a crime. The program maps the individual's distinct anthropometric landmarks, and then superimposes the images over the original 2-D image and the newly created 3-D model. This process reduces the influence of facial orientation, which allows for a more accurate identification.[55]

Forensic Odontology

Forensic odontology involves examining, handling and evaluating dental evidence, typically to identify the deceased by their dental remains or to prove a crime. Essentially, this specialty applies dental principles to legal issues. Possibly one of the most notorious cases of forensic odontology is that of Adolf Hitler. After the bombing of the Wolf's Lair bunker in 1944, Hitler had persistent headaches and had 3 radiographs of his skull in an attempt to cure his ailment. The dental impressions visible on the radiographs were highly unusual and investigators later positively identified Hitler through comparison with burned remains.[1] Dental identification relies on comparison of antemortem with postmortem radiographs to establish patterns of missing, filled or decayed teeth. Radiographs also show variations in anatomy or dental work. Unlike written records, radiographs supply objective data in the form of anatomy.[56]

Forensic odontology also can assist with facial reconstruction to identify the deceased. According to Stephan and Henneberg, determining mouth width using the canine teeth alone may be the most accurate technique for facial approximation and reconstruction.[57] This varies from the traditional opinion that facial approximation is best determined by measuring the medial distance between the centers of the pupils that correlate to the width of the mouth. This theory relies on soft tissues, which can be problematic in cadavers.[58] Instead, the authors suggest basing these estimates on hard tissue, in particular the canine teeth and intercanine width.[57]

Ethical and Legal Considerations

In general, the same regulations, standards and codes of conduct apply to forensic examinations of the living and deceased and clinical examinations of the living. These include relevant codes of conduct and regulations regarding radiation and standards and regulations concerning informed consent and privacy. In addition, documentation policies and procedures extend to the importance of maintaining continuity of evidence.[2]

Ethics

The ethical codes that apply in the clinical setting are relevant to forensics. This includes, among others, the American Registry of Radiologic Technologists Standards of Ethics and the American Society of Radiologic Technologists Code of Ethics. When applying these codes within the forensic setting, radiologic technologists more often interact with family members of the deceased than directly with a patient. In regards to forensic examinations in the living, many physician associations may address confidentiality and other ethical issues in their codes of ethics. For example, the American Psychological Association's code states that forensic practitioners should notify clients about the limits of confidentiality, potential legal uses and disclosures of information, the purposes of service and any alternatives to service, ie, the right to remain silent.[59]

Consent

Consent generally is defined as giving assent or approval, and a person must consent to an examination of any kind before it can legally be performed in the United States. Consent can be given by the individual undergoing a procedure, the individual's parent or legal guardian if the individual is incapacitated or deceased, or someone the court appoints, such as an individual's next of kin or executor. Special consideration should be given to issues that can arise when obtaining consent from a parent suspected of child abuse, a psychiatric patient or a drug trafficker who is impaired because of toxicity from faulty body packing and who needs emergency care.[60]

Consent varies for medical-legal forensic autopsies and hospital autopsies. A forensic autopsy requires prior consent from a family member or other authorized person. If the family of the deceased objects to dissection, a medical examiner or coroner may perform only an external examination when there is adequate background information and it will not compromise a criminal investigation. When cause of death is not apparent, a complete internal examination is essential, and often mandated by the state, for a medical-legal investigation. When a death occurs in a clinical setting, consent for an autopsy must be obtained before a pathologist can perform the procedure. Because the cause of death usually is known in a clinical setting, autopsies may be performed for research or educational purposes.[60]

Several states have specific statutes limiting and sometimes preventing forensic examination when religious beliefs are the reason that a victim's family does not consent to an autopsy. In Judaism, for example, 2 views regarding the deceased prevail. Traditional Orthodox Jews believe that the human body must remain intact even after death. The reason for performing an autopsy must be readily apparent, such as to save another human life that is in immediate danger. The second, more liberal, view is that an autopsy still may serve the dead by providing information about disease and other illnesses that ultimately serves humanity.[61]

When an autopsy is refused, the forensic pathologist should not move forward with the dissection until a compelling legal reason is established that requires an autopsy. In addition, other methods of examining the victim may be appropriate, such as crime scene investigation, external examination, toxicology, endoscopy, forensic radiography or virtual autopsy.[61]

Health Insurance Portability and Accountability Act

Disagreement in the literature relates to whether the deceased are covered entities under the Health Insurance Portability and Accountability Act (HIPAA). According to HIPAA, individuals covered under the law receive care, along with health care services or supplies related to an individual's health. This includes preventive, diagnostic, rehabilitative, maintenance, counseling, assessment or palliative care that affects the structure or function of the body. Questions also surround the classification of forensic findings as protected health information. Forensic services, however, generally are not under the umbrella of health care, because they are carried out for a legal purpose and health care insurers do not pay for the procedures. Furthermore, even though forensic services render diagnoses or assessments, they do not treat.[59]

Despite these arguments, it is safest to act as if HIPAA rules for the clinical setting also apply in the forensic setting.[2] Furthermore, forensic practitioners typically exceed the privacy expectations HIPAA sets forth, particularly concerning consent for disclosure of information. For example, it is highly unlikely that a forensic practitioner would release confidential information without signed consent or a court order.[59]

Naturally, radiologic technologists conducting forensic radiography examinations in the clinical setting must follow HIPAA regulations.[2] According to Connell et al, the privacy rules and security standards of HIPAA offer useful tools for handling forensic information. The standards are intended for anyone who maintains or transfers health information so that reasonable and effective safeguards are maintained to prevent unnecessarily disclosing information, even when it may not be classified as protected health information. Guidelines are provided for the handling of information that potentially could jeopardize an individual's confidentiality. These actions may be as simple as leaving patient data on a computer monitor in a public area, making audible phone calls that relate to a case or mailing information to litigants.[59]

HIPAA privacy rules also contain useful guidelines on which identifying information to remove from protected health information and other records, including such obvious items as the Social Security number of an individual and identifiers such as the ZIP code of a patient's residence if a geographical area contains <20 000 residents. Authorization to release information also is an important aspect of these rules and is highly relevant to forensic practitioners, who rely heavily on third-party information. Proper authorization cannot be combined with any other documentation (ie, notice of privacy practices), should be written in plain language and must include all the following:

- A description of the information or protected health information to be used or disclosed.
- The identities of the person or group of people authorized to apply or disclose the information.
- The identities of the person or group of people the individual or covered entity authorized to make the use or disclosure.
- A description of each purpose of the use or disclosure.
- An expiration date or event.
- The individual or covered entity's signature and date; if signed by a representative, a description of the representative's authority to act on behalf of the individual or covered entity.[59]

In summary, nearly everyone working in medicine or the health care industry, including those in forensic medicine and forensic radiography, must comply with HIPAA. A violation can result in a fine ranging from $100 to $25 000 or more than 10 years in prison, or both.[59]

Chain of Evidence

In forensic radiography, radiologic technologists should follow strict procedures and standards to ensure that the imaging results are valid; the continuity, or chain, of evidence is established; and evidence is admissible in a court of law.[47] It also should be noted that everything related to a crime or crime scene — including physical items and a cadaver — is considered subjustice, meaning subject to investigation under the law. Any items of potential evidence must be retained and preserved as much as possible. For example, radiologic technologists and radiologist assistants should not cut clothing in an area apparently torn or perforated by a bullet or knife blade. Forensic radiography personnel also should not remove bags from the hands of the individual, because the hands are bagged to preserve evidence. All articles belonging to the deceased should be passed to appropriate law enforcement personnel. Many facilities have a protocol that includes photographing the deceased person before any radiologic imaging is performed. If the deceased person's jewelry must be removed, a photograph of the items should be taken before the radiologic technologist, or any other person removes the jewelry. The jewelry should be retained as potential evidence.[2]

Proving continuity of evidence requires that a radiologic technologist, along with a witness, state in a court of law that he or she produced the images in question at a specified date and time, that the images are of the individual in question and that no one tampered with the images during or after the imaging process. The images should be marked with the date, time and location that they were rendered and should feature correct anatomical markers.[2]

Expert opinion also may be needed to accurately interpret radiologic findings in a court setting so that the images do not add unwarranted weight to a testimony. Although radiologic images may appear to provide objective evidence, the significance of the evidence sometimes is questionable, and the court typically does not have the specialized scientific expertise to correctly understand radiologic findings.[62]

The radiologic technologist may be called as an ordinary or expert witness for the defendant or plaintiff in litigation that concerns liability. Liability cases can relate to professional liability (malpractice) or personal, property or product liability. Expert testimony involving radiologic technologists most commonly is required for personal injury cases. It also might be required in cases of wrongful death or civil rights violations and testimony sometimes may be given outside a court of law.[20]

Forensic Radiography Considerations

Radiation Safety

Radiation safety standards also should be applied when imaging the deceased.[63] As in the clinical setting, anyone involved in forensics — radiologic technologists, radiologists, pathologists, medical examiner staff members and all others — should exercise caution when dealing directly or indirectly with ionizing radiation.[2] Radiation-reducing techniques, such as ALARA (as low as reasonably achievable), should be considered, along with applicable local, state and national guidelines and regulations.

Anyone conducting a forensic radiography exam must follow the 3 cardinal rules of radiation safety — time, distance and shielding. The radiologic technologist should use the least amount of time necessary to obtain a quality image. The minimum distance from the radiologic equipment during imaging should be at least 6 feet from the source. Finally, all personnel involved in the imaging process must always wear protective equipment, including proper lead aprons, or otherwise be shielded by permanent or portable lead barriers.[2]

Positioning

Positioning the deceased for imaging examinations differs from positioning living patients. When imaging helps determine cause of death or identifies the deceased, the subject should be imaged in a projection as close to actual anteroposterior (AP)/posteroanterior (PA) as possible. A lateral projection also is helpful. The radiographer should try to examine the skull in true AP and lateral projections to demonstrate the frontal sinuses and the sella turcica if the radiograph is for identification. Every joint should be included in full-body imaging because orthopedic appliances or degenerative changes can aid in identification and the thoracic and abdominal cavities may contain stents or pacemakers. Conditions such as arthritis or previous fractures unique to an individual also may assist in identification. Placement of correct anatomical markers is crucial to this process.[2]

Imaging Skeletonized Anatomy

Techniques for imaging soft tissue in the early stages of decomposition are similar to those applied in imaging the living. As tissues continue to decompose, however, gas is produced. This can affect imaging technique. If remains are skeletonized, imaging systems that provide wide exposure latitude and sharp image detail are ideal. If such equipment is not available, techniques that can improve image quality include increasing source-to-image receptor distance or using a small focal spot, close collimation, optimal kilovolt peak or sufficient milliampere seconds.[2]

When skulls dry, they lack soft tissue, which usually leads to overexposure of radiographs. It also can be difficult for the radiologic technologist to maintain the cranium, with or without the mandible, in the correct position. A substitute spinal column may be constructed or acrylic hooks and rubber bands can be used to hold the separate parts of a partially decomposed or incomplete skull in their correct anatomical place.[64]

Imaging Mass Casualties

When radiology is used in response to mass casualty events, such as hurricanes or airplane accidents, the examination usually focuses on identifying the deceased. The condition of the bodies of mass disaster victims varies based on the event. For example, bodies of hurricane victims generally are more intact than those of people killed in an airplane crash or bombing, whose bodies typically are burned and more fragmented. In the event of a biologic or radiologic event, precautions should be taken to rule out the risk of contamination before forensic imaging examinations begin.[2]

The increasingly important role of forensic radiography in responding to mass casualties has evolved over the years. Today, radiography and CT can be used in many disaster mortuaries, and even at the scene of mass disasters. MR imaging also is valuable for imaging mass disaster victims, but presents more problems in terms of portability and scanning body parts that contain metallic fragments. When conducting forensic radiography examinations for mass casualties, a forensic protocol may consider the following[65]:

- Cause of death.
- Documentation of injuries.
- Documentation of existing (natural) diseases.
- Notation of the presence of identifying items (identifying surgical implants or personal possessions) and their location.

- Notation of health and safety issues (hidden weapons, infectious disease).
- Autopsy planning.
- Collection of forensic radiography examination evidence.

Additionally, forensic radiography support of mass casualty incidents may involve determining presence, nature and location (path) of projectiles or imbedded objects and examining inanimate materials.[65]

Challenges

Forensic radiology still is not formally recognized as a branch of forensic science. The field lacks radiologists,[66] with budget constraints often forcing forensic pathologists to interpret radiographic images instead. To assess the ability of nonradiologic forensic pathologists, a study was conducted in which pathologists reviewed all children's deaths within a 1-year period in Quebec, Canada. Experienced pediatric radiologists reviewed 20 cases, and the researchers compared those interpretations with the pathologists'. In 3 cases, pathologists missed an important finding. Investigators deemed this rate of misinterpretation alarming and suggested that the lower interpretation quality was not worth the potential cost savings to forensic facilities, thereby underscoring the importance of a radiologist in the forensic setting.[67]

When radiologists work in the forensic setting, their technical understanding of imaging must be coordinated with forensic pathologists' knowledge of the postmortem changes in a corpse.[4] Because CT and MR imaging increasingly are being used in forensics, radiologists must recognize the difference between postmortem imaging and clinical imaging. The risk of misinterpreting the findings increases when clinical knowledge is used exclusively; therefore, it benefits an investigation for a radiologist to work in conjunction with a pathologist. Whole-body CT likely is used more often in routine forensic autopsy owing to its ability to accurately detect abnormalities, such as hematoma, abnormal gas collection, fractures and metallic foreign bodies. MR imaging is more problematic in the deceased, but its improved tissue contrast compared with CT makes it useful in investigating cranial, thoracic and abdominal cavities, as well as in detecting hematomas in soft tissue. Further research and efforts are needed in forensic radiography to advance understanding of the application of radiologic modalities in forensic cases and for the recognition of forensic radiography as a valid and important subspecialty in forensics.[68]

In 2008, the ASRT conducted the ASRT Forensic Radiography Survey, receiving responses from 77 members of the National Association of Medical Examiners. Of the respondents, 88.3% reported using radiographic equipment at their facilities. Approximately 34% stated that a registered radiographer conducted their imaging examinations. Pathologists, forensic assistants and other medical examiner and coroner office staff members also performed radiography.[69] Cross-utilization and cooperation between forensic and radiology departments may be a valuable approach for smaller forensic facilities that cannot afford to hire a radiologist or radiologic technologist or the budget to acquire equipment such as CT scanners. This would help forensic facilities conduct quality imaging examinations and receive skilled interpretation of findings without devoting financial resources to equipment and training.[31] See Box 2 for a list of organizations that have information on forensic radiography.

Working Conditions

Many forensic radiography examinations occur in a morgue or a medical examiner's facility. Resources and equipment available vary depending on the budget. In disaster situations, a temporary facility may need to address immediate forensic investigations. A temporary facility may consist of a tent, or several tents, with limited supplies. Radiology equipment may be scarce or vary and deployed radiologic technologists may work long hours. Medical examiner offices may need to schedule call and after-hours services may be necessary, especially in cases of homicide or local mass casualties and disasters.[2]

Because forensic investigations can involve examining the dead, radiologic technologists should use universal precautions when dealing with any type of body fluid, and cadavers should be treated as potentially infectious. All personnel should have up-to-date vaccinations for hepatitis and tetanus.[2]

Emotional Effects

Working with the deceased can affect the emotional well-being of radiologic technologists. In fact, posttraumatic stress disorder (PTSD) is common among people working in forensics.[70] PTSD is characterized as an anxiety disorder that develops after exposure to a terrifying event in which grave physical harm occurred or was threatened. According to the National Institute of Mental Health, events that can trigger PTSD include violent personal assaults, natural or human-caused disasters, accidents or military combat.[71]

Box 2
Forensic Radiography Resources

Several radiologic organizations recognize the value of forensic radiography. These organizations also offer valuable information on the topic and promote initiatives and development in the field. Organizations that serve as resources include:

- International Association of Forensic Radiographers.
- American Academy of Forensic Sciences.
- American Roentgen Ray Society.
- Radiological Society of North America.
- Forensic Science Commission.

In a study of rescue or disaster workers exposed to airplane crash events compared with workers not exposed to disasters, incidence of acute stress disorder, PTSD and depression were significantly higher in exposed workers. At 13 months, 40.5% of workers exposed to mass casualty events were diagnosed with all 3 conditions vs 20.4% of unexposed workers. Workers who were younger and single were more likely to develop acute stress disorder. In addition, more of the exposed workers sought medical care for their emotional conditions (see Table 2).[72]

Forensic Initiatives

Forensics extends well beyond the medical and scientific sphere into such areas as investigating genocide, military atrocities and other human rights violations. According to the National Institutes of Health, forensic human rights investigations are currently underway in more than 30 countries. These investigations use archaeology, forensic anthropology, pathology, odontology, ballistics, computer modeling and DNA analysis to prove and document mass murder and genocide, along with identifying the victims and the people responsible.[47]

The international Forensic Anthropology Team has investigated government military and paramilitary forces suspected of committing political murders, genocide, torture and other atrocities in North and South America, Asia, Africa and Europe. The findings have been presented in criminal trials, to international tribunals and national truth commissions. Following the lead of the Forensic Anthropology Team, other associations have formed to conduct forensic investigations of human right violations, such as the International Forensics Program of Physicians for Human Rights, Inforce and the Latin American Forensic Anthropology Association.[47]

Conclusion

Forensics applies scientific principles to criminal matters that concern the living and the dead. Many specialized areas fall under the umbrella of forensics — including forensic medicine, forensic anthropology, odontology and, although not formally recognized, forensic radiography. This is a growing subspecialty with an important place in forensics. Applying radiologic technology to criminal investigation can yield information otherwise unavailable. Although radiography is the most common modality used today, CT scanning, MR imaging and other modalities show great promise.

Forensic radiography is applied in a variety of circumstances, including but not limited to, augmenting nonfatal court cases (eg, smuggling, authenticating documents, artwork, jewels and other artifacts) and assisting with fatal cases of homicide (eg, determining cause of death or identifying the deceased).[1,2,6,7,20]

Table 2
Significance of Stress Disorders and Depression in Disaster or Rescue Workers Exposed to Plane Crash Events[72]

	Exposed Workers (N=19) (%)	Workers Not Exposed (N=51) (%)	*P* Value
Depression			
At 7 months	16.4	10.0	.05
At 13 months	21.7	12.6	<.03
Acute stress disorder	25.6	2.4	.001
PTSD at 13 months	16.7	1.9	.001
Incidence of all 3 conditions at 13 months	40.5	20.4	.001

PTSD, post-traumatic stress disorder.

Additionally, forensic radiography is noninvasive and demonstrates the internal body without dissection, which is beneficial when religious or cultural beliefs prohibit opening bodies of the deceased.[47,61] Drawbacks include the cost of equipment and the lack of trained personnel to conduct and interpret radiologic images in many settings.[2]

For radiologic technologists, rules of radiation safety apply when imaging the deceased and the living. Care also must be taken to preserve the resulting images as evidence and to ensure that they are admissible in a court of law. Guidelines for privacy, consent and ethical behavior apply as well.[2]

Many challenges are associated with working in the field of forensics, such as budget limitations, harsh working conditions and the emotional impact of working with the deceased.[2] Improved recognition of the value of forensic radiography and the emergence of several forensic radiology organizations have facilitated advances in the field. Furthermore, radiologic technologists who work in forensics likely will benefit from knowing that their work may put to rest questions surrounding a victim's death, thereby bringing peace to the victim's loved ones.

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